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SPECIFICATION

TITLE OF THE INVENTION

SAPPHIRE SINGLE CRYSTAL ~~MONOCRYSTAL~~, SEMICONDUCTOR LASER DIODE USING THE SAME FOR SUBSTRATE, AND METHOD FOR MANUFACTURING THE SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a sapphire single crystal ~~monocrystal~~ provided with a smooth cleavage plane, more particularly, to a single crystal ~~monocrystal~~ sapphire substrate easier to cleave, so as to be used as a substrate, of thin film growth, such as semiconductor or the like, for electronic parts or structure parts, and to a method of working the same. Furthermore, the invention relates to a semiconductor laser diode using such a single crystal ~~monocrystal~~ sapphire substrate and a method of manufacturing the same.

2. Prior Art

The sapphire single crystal ~~monocrystal~~, i.e., Al_2O_3, is used for usage of wider range, because it has higher clear-degree, hardness and comparatively smoother plane. The sapphire of the single crystal ~~monocrystal~~ is pulled, growing a seed crystal in contact with the surface of the molten alumina to produce

the ~~monocrystal~~ single crystal into a larger monocrystal, so as to generally work the ~~monocrystal~~ single crystal into the desired shape.

A method of working the sapphire ~~monocrystal~~ single crystal comprises mechanical working such as grinding, abrading or the like with the use of diamond grindstone, diamond grinding ~~gains~~ grains, chemical etching working with the use of corroding phenomena, and furthermore, ~~growing finer~~ enlarging a fine microcrack, formed on the surface with a diamond needle point pen tip, so as to effect a cleaving, breaking operation.

~~Such~~ With the working methods as described above ~~are~~ it is difficult to obtain a smooth~~er~~ surface in a short time. The mechanical working with diamond grindstone is longer in working time and is higher in working cost. The chemical etching operation, which has an advantage ~~capable~~ of easily compensating the sapphire face smoothly, takes approximately 10 hours for effecting ~~the~~ etching operation ~~of~~ 1 mm in thickness, and it is hard to obtain ~~the~~ a smooth face of sub-micron ~~unit~~ level. Also, the breaking, working method with the diamond needle point pen tip is worse in the accuracy of the worked surface, and it is difficult to obtain ~~the~~ a smooth face.

The sapphire ~~monocrystal~~ single crystal is used to form ~~the~~ a laser light emitting element, composed of multiple semiconductor layers, on the surface of the substrate ~~as a substrate of the semiconductor laser element~~. In the semiconductor

laser diode, whose schematic structure is shown in Figs. 6 and 7, a semiconductor multilayer 3 forming for composing the laser light emitting element is disposed on ~~formed through~~ a buffer layer 2 on the surface of the single crystal ~~monocrystal~~ sapphire substrate 1 to act as ~~have~~ a resonator for the ~~of~~ laser beam between a pair of opposite end faces 3a ~~and 3a~~ of the multilayer 3. The pair of end faces 3a ~~and 3a~~ are smooth reflection end faces extremely high ~~higher~~ in precision and simultaneously, the parallelism of both the faces is required to be extremely high ~~made higher~~, so as to improve the oscillation efficiency.

Although a method of growing a semiconductor thin film on the major plane of the single crystal ~~monocrystal~~ sapphire substrate to form patterns, and then, dividing ~~diving~~ the substrate into a chip shape is used to produce, generally, the semiconductor element including a laser diode, the above described conventional methods are hard to use ~~divide~~ with ~~better~~ precision, so as to reduce the yield of ~~producing~~ the chips. Although the chip division plane is used as the reflection end face, especially when the semiconductor thin film is grown further into a multilayer on the substrate, and then, divided into chips with each ~~for every~~ substrate as the semiconductor laser diode, the higher precision of a sub-micron level required ~~to be demanded~~ for the reflection end face cannot be achieved by the above described working method.

As for this problem, although Japanese Patent Application Laid-Open A7-27495 discloses that the ~~monocrystal~~ single crystal sapphire substrate is cleaved, divided into parallel to the axis C <0001> of the sapphire crystal, this method is incapable of obtaining ~~the~~ a smoother surface of high precision.

An object of the invention is to provide, first, a sapphire ~~monocrystal~~ single crystal having a smoother division plane higher in precision, and a ~~monocrystal~~ single crystal sapphire substrate.

Another object of the invention is to provide a dividing method ~~of~~ for a sapphire ~~monocrystal~~ single crystal capable of forming such a precise division plane in short time on the sapphire ~~monocrystal~~ single crystal.

Still another object of the invention is to provide a semiconductor laser diode provided a precise smooth plane on the end face of the resonator of the ~~monocrystal~~ single crystal sapphire substrate.

A further object of the invention is to provide a method of forming a precisely smoother plane on the resonator end face of the ~~monocrystal~~ single crystal sapphire substrate to manufacture a semiconductor laser diode.

SUMMARY OF THE INVENTION

The invention applies a plane R to the formation of the smoother surface of the sapphire ~~monocrystal~~ single crystal with the

use of a fact where the plane R of the sapphire single crystal ~~monocrystal~~ is easier to cleave and the cleavage plane is a smooth plane of higher precision. Now, the R Plan ~~plate~~ is referred to as the (1102) ~~(1 - 102)~~ plane indicated with hexagonal indices.

The sapphire single crystal ~~monocrystal~~ having such a plane R for the cleavage plane includes a sapphire tool, the other structure members or a single crystal ~~monocrystal~~ sapphire substrate having the cleavage plane on its side face. Such a sapphire single crystal ~~monocrystal~~ plate is used as a single crystal ~~monocrystal~~ sapphire substrate whose major plane has elements such as semiconductor elements, functional elements and so on.

The invention detects the plane R existing within the sapphire single crystal ~~monocrystal~~ body to cleave along the plane R, so as to divide the single crystal ~~monocrystal~~ body and have it on the surface of the smooth plane R on the single crystal ~~monocrystal~~ body. To simplify division of the sapphire single crystal ~~monocrystal~~ body or the substrate by the cleavage, the invention includes an index, for controlling the plane R in the dividing, with the reference plane related to the plane R being formed in, for example, the single crystal ~~monocrystal~~ body or, for example, the edge portion of the substrate, by previous specification of the plane R of the single crystal ~~monocrystal~~ sapphire in the X-ray crystal study.

More concretely, in the example of the single crystal ~~monocrystal~~ sapphire substrate, the reference plane which is

substantially parallel to or substantially vertical to the plane R is provided on the periphery of the substrate. For the cleaving operation, a method is adopted for forming a linear crack which is parallel to or vertical to the reference plane of the substrate is formed, and having the microcrack line as a start point to develop ~~the~~ a crack in the thickness direction for a cleaving operation.

Also, in the ~~monocrystal~~ single crystal sapphire substrate of the invention, the ~~monocrystal~~ single crystal sapphire substrate where the semiconductor multilayer is formed is cleaved, separated along the plane R to form a cleavage plane connected with the semiconductor multilayer and the substrate in a substrate where a laser diode is formed for forming the semiconductor multilayer on the major ~~plate~~ plan of the substrate. The cleavage plane of the semiconductor multilayer is also an extremely smooth plane. The invention uses it for the reflection ~~lane~~ plane for laser resonator use of the semiconductor multilayer.

A semiconductor laser diode using the ~~monocrystal~~ single crystal sapphire substrate of the invention comprises a semiconductor multilayer composing a laser element on the major plane of the ~~monocrystal~~ single crystal sapphire substrate, and is characterized in that two reflection end planes for composing the resonator of the laser beam in the multilayer

are cleaved planes connected with the cleaved plane along the plane R of the crystal of the ~~monocrystal~~ single crystal substrate.

A method of manufacturing a laser diode of the invention comprises steps of using a ~~monocrystal~~ single crystal sapphire substrate provided with the reference plane, forming the semiconductor multilayer for emitting the laser beam the multiple on the major plane, then cleaving the ~~monocrystal~~ single crystal sapphire substrate and the semiconductor layer along the R face with the reference plane of the sapphire ~~monocrystal~~ single crystal as an index. By this method, they are divided quickly and easily into many laser diode chips provided with smooth cleaved face on both the end planes of the semiconductor multilayer.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is to be explained for further description with reference to the following drawings.

Fig. 1 is a sapphire crystal structure;

JM 5/14/02 ~~Fig. 2 shows~~ Figs. 2A-2C show a front view (A) and a side view (B) of a ~~monocrystal~~ single crystal sapphire substrate wherein a reference plane is provided on the substrate side face, a microcrack line vertical to the plane R and parallel to on the major plane of the substrate;

JM 5/14/02 ~~Fig. 3 shows~~ Figs. 3A-3C show a front view (A) and a side view (B) of a ~~monocrystal~~ single crystal sapphire substrate where a microcrack line is

formed in part on the end portion side of the substrate top plane, and a side view (C) in a cleaved condition;

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~~Fig. 4 is~~ Figs. 4A-4B show a similar view to the ~~monocrystal~~ single crystal sapphire substrate view 2 whose substrate is rectangular;

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~~Fig. 5 shows~~ Figs. 5A-5B show the arrangement of the plane R when the major plane of the rectangular substrate is a plane C;

Fig. 6 is a perspective view showing the structure of the laser diode of a gallium nitride system double hetero bonding type; and

Fig. 7 is a sectional structure of a laser diode of a double hetero bonding type; and

Fig. 8 shows the arrangement of the plane R when the major plane of the rectangular ~~monocrystal~~ single crystal sapphire substrate is made ~~an~~ on plane A.

DETAILED DESCRIPTION OF THE INVENTION

In the crystal structure of a sapphire, as shown in Fig. 1, the sapphire crystal is a hexagonal system, wherein a axis C for forming a central axis, a plane C (0001) vertical to it, an axis A (axis a_1, axis a_2, axis a_3) to be extended in three directions vertically from the axis C and respectively vertical ~~plane A (11 - 20)~~ plane A(1120), and the ~~plane R (1 - 102)~~ plane R (1102) oblique at a constant angle to the axis C, and a axis R vertical to it exist when the major axis and plane of the crystal system are expressed with hexagonal indices.

The planes and axes of the sapphire can be analyzed with X ray diffraction and can be determined about the actual sapphire ~~monocrystal~~ single crystal.

The plane R of the actual sapphire ~~monocrystal~~ single crystal is easier to cleave and the cleavage plane is a smooth plane of extremely high precision, whereby the sapphire ~~monocrystal~~ single crystal body or the sapphire ~~monocrystal~~ single crystal plate can be used as a surface of higher precision and higher linearity by cleaving along the plane R. In this example, a sharp edge formed by the working plane and the cleavage plane of the plane R can be used as a sapphire tool as described later.

Also, the sapphire ~~monocrystal~~ single crystal ~~is widely~~ may be used as a sapphire plate having a cleavage plane, parallel to the plane R, as a side plane, or especially as a sapphire plate substrate.

To use the plane R of the sapphire ~~monocrystal~~ single crystal for the cleavage plane, a means for realizing the plane R of the crystal on the actually desired surface is required ~~to provide~~. In one embodiment of the invention, ~~and~~ a reference plane 12 parallel or vertical substantially to the plane R detected the sapphire ~~monocrystal~~ single crystal in advance is provided in advance in the sapphire ~~monocrystal~~ single crystal plate 10. When the ~~monocrystal~~ single crystal plate is a substrate to be used for forming the semiconductor layer or the like on the major

plane 11, it is convenient to form the reference plane 12 as the side end plane as part of the peripheral edge portion of the sapphire monocrystal plate or a monocrystal sapphire substrate.

The reference plane substantially parallel to or vertical to the plane R is ~~in an angle range~~ within ±10° from an orientation parallel or vertical completely to the plane R in the reference place, and especially, is preferable to be within ±2° ~~in angle range~~.

More concretely, the sapphire substrate 10 will be described hereinafter. As shown in Fig. ~~2 (A)~~ 2A, the major plane 11 of the ~~monocrystal~~ single crystal sapphire substrate 10 is parallel to the plane A (11 - 20) and parallel to the axis R. The reference plane 12 is formed parallel to the axis R, namely, is formed vertical to the ~~plane R (1 - 102)~~ plane R(1$\bar{1}$02) on the side face of the substrate. Thus, the plane R is vertical to the major plane 11, and is vertical even to the reference plane 12. Furthermore, the axis C is formed at an angle of 57.615° to the reference plane 12. In this manner, the sapphire ~~monocrystal~~ single crystal formed on the reference plane 12 can be used as the substrate for forming the element such as semiconductor element or the like.

To cleave and divide the ~~monocrystal~~ single crystal sapphire substrate, a linear microscopic scratch flaw, i.e., microcrack line 13 is ~~drown~~ drawn in a direction vertical to the

reference plane 12 on the main plane 11 (or its reverse plane) with the use of a diamond needle point pen to form a crack starting point on the surface. Since the reference plane 12 forms ~~is in a direction of forming~~ an angle of 32.383° with respect to the axis C, i.e., in the axis R direction, the microcrack line 13 vertical to the reference plane 12 is within the plane $(1\text{-}1\bar{1}02)$ ~~plane R (1 - 102)~~, i.e., the direction of the microcrack line 13 becomes a direction of the plane R$(1\bar{1}02)$ ~~plane R (1 - 102)~~. Actually, an error between the orientation of the microcrack line 13 and the orientation of the plane R is to be within ±10°, and preferably within ±5°.

Then, ~~apply~~ a bending stress in a direction of widening the microcrack line 13 is applied upon the single crystal ~~monocrystal~~ sapphire substrate 10, and a crack along the microcrack line 13 grows ~~is grown~~ rapidly in the thickness direction of the substrate ~~and is cleaved~~ as in Fig. 2B ~~2 (B)~~, so as to divide the substrate 10 into two parts. The planes on both the sides where the crack is formed become cleavage planes ~~14 and 14~~ parallel to the plane R (Fig.2C). In this example, the cleavage plane is vertical precisely to the major plane 11. Since the cleavage plane is ~~in a condition~~ aligned at an atomic level, Strightness ~~the linear property~~ and Smoothness ~~the smooth property~~ can be obtained at a ~~in~~ sub-micron level ~~unit~~. Actually the measured value of the division plane, in surface roughness (Ra),

cleaved along the plane R becomes 10Å or less ~~lower~~, depending upon the conditions of the division.

In the substrate shown in Fig. 2, ~~grow~~ the sapphire is grown by an EFG method (Edge-Defined Film-Fed Growth Method) of setting a seed crystal wherein a pulling axis is made the axis R<1102> ~~axis R <1 - 102>~~, and the major plane is made the plane A (1120) ~~(11 - 20)~~ within a melting furnace (see Fig. 1). Then, ~~cut~~ the monocrystal is cut in a pulling direction, namely, vertically to the axis R ~~and conduct a precise working operation~~, and a disk (for example, 50 mm in diameter, 0.425 mm in thickness) where the orientation flat is made parallel to the axis R and the major plane is made an plane A is easily obtained. The crystal precision of the material is obtained by managing ~~of~~ the seed crystal.

As shown in Fig. 3A ~~3 (A)~~, the microcrack line 13 ~~to be~~ formed by a diamond needle point pen can be formed partially only in the peripheral edge portion (for example, in the range of 5 through 20 mm from the edge end portion in the example of the substrate of 50 mm in diameter) of the crystal sapphire substrate 10. In this manner, the damaged portion of the substrate surface by the microcrack line can be made minimum, so as to improve the yield of the chip after the division thereof. Even in this case, as shown in Fig. 3B ~~3 (B)~~, application of ~~apply the~~ bending stress to ~~upon~~ the single crystal ~~monocrystal~~ sapphire substrate for growing ~~of~~ a crack in

the thickness direction and extension ~~the extending direction~~ of the microcrack line, and Straightness and Smoothness ~~the linear property and smooth property of~~ at the sub-microscopic level ~~unit~~ can be obtained ~~as~~ in the cleavage plane of ~~with~~ the substrate after the division thereof on ~~being a cleaved plane in~~ both the planes of the crack.

In Fig. 4, an example of rectangular single crystal ~~monocrystal~~ sapphire substrate 10, the major plane 11 is ~~an~~ plane A, one reference plane 12a is formed to be parallel to the plane R, and another reference plane 12b is formed to be vertical to the plane R. Therefore, form a microcrack line 13 in a direction parallel to the reference plane 12a and apply ~~the~~ bending stress for widening the microcrack line 13, and the substrate 10 is cleaved along the plane R, so as to divide it. The rectangular single crystal ~~monocrystal~~ sapphire substrate 10 having the reference planes 12a and 12b parallel or vertical to the plane R in this manner can use the surface area effectively.

In this manner, form the reference plane 12, in a direction vertical to or parallel to the plane R, on the single crystal ~~monocrystal~~ sapphire substrate 10, and the direction of the plane R can be obtained easily. Form the microcrack line 13 relative ~~related~~ to the reference plane 12 on the major plane and break it for a cleaving operation, and parallel plural or multiple microcrack lines ~~line~~ 13 can be formed and the substrate

10 can be divided into ~~plural or~~ multiple ~~ones~~ parts easily. In this manner, an efficient dividing operation of the substrate can be conducted by the previous forming of the reference plane vertical or parallel to the plane R on the ~~monocrystal~~ single crystal sapphire substrate.

Such a ~~monocrystal~~ single crystal sapphire substrate 10 as shown in Fig. 5 is rectangular, whose major plane 11 is made a plane C, and the reference plane 12 is made vertical to the plane R. Therefore, form a microcrack line 13 in a direction vertical the reference plane 12 on the major plane 11 (or on the reverse plane approximate parallel to the major plane) and apply the bending stress, and it can be cleaved, divided along the plane R. In this case, as shown in Fig. 5A ~~5~~, to form the angle of 57.615° between the plane R, parallel to the cleavage plane, and the major plane 11, it is inclined in the thickness direction and divided as in Fig. 5B ~~5 (B)~~. Since the sharp edge is formed between the major plane 11, as the working plane, and the cleavage plane 14 ~~of the division plane~~, such a substrate can be used for a sapphire tool such as cutter, tape cleaner or the like.

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In the invention, the reference plane 12 in a direction vertical or parallel to the plane R is such that the reference plane 12 stays within the range of the angle in ±10° or ~~lower~~ less from a position completely vertical or

parallel to the plane R(1$\bar{1}$02) ~~R (1 - 102)~~, and preferably, within ~~in~~ ±2° or less ~~lower~~.

Also, although the major plane 11 for forming the microcrack line 13 is not usually necessary to be ~~made~~ the plane A or the plane C, it is preferable ~~preferably~~ to have the major plane as a mirror plane of 0.1 μm or lower in surface roughness (Ra) although any orientation relation is allowed. This is why the major plane 11, if rough after the ~~a~~ rough working operation thereof, interferes with the crack growth of the microcrack line formed due to existence of innumerable microcrack line on the surface.

A method of propagating the crack comprises a method of applying such mechanical bending deformation as described above, and a method of applying ~~a~~ laser beam irradiation ~~irradiating~~ operation, hot ~~a heating~~-wire heating ~~operation, an~~ infrared rays lamp irradiation ~~irradiating operation~~ or the like upon the major plane along the microcrack line to cause ~~causing~~ thermal stress ~~stressing~~, and using the stress ~~stressing~~ for induction of the crack growth.

The single crystal ~~monocrystal~~ sapphire substrate obtained in the above description can be available in various fields, because the substrate has a smooth plane R in cleavage plane by cleaving and separating along the plane R. As the range for application, a method of forming the thin film of the semiconductor or the like in advance on the major plane

a of the ~~monocrystal~~ single crystal sapphire substrate 10, then cleaving, separating operations along the plane R, and dividing a plurality of elements can be widely used.

In the other embodiments of the invention, the a ~~monocrystal~~ single crystal sapphire substrate provided with the cleavage plane of such a plane R as described above can be used suitably as the substrate for the laser diode use. Namely, in the semiconductor laser diode, a semiconductor multilayer for forming the laser light emitting element is formed by the epitaxial growth on the major plane of the a ~~monocrystal~~ single crystal sapphire substrate to make the substrate a cleavage plane, cleaved along the plane R so that the cleavage plane of the growth layer continuous to the cleavage plane at the same time even to the semiconductor multilayer on the substrate. Although two side planes of the semiconductor multilayer are the cleavage planes of the semiconductor multilayer, the cleavage planes are also 6 planes ~~smooth~~ extremely smooth ~~in~~ at the atomic level, thus resulting in the mutually opposite reflection planes of the resonator.

For an optical resonating operation, it is suitable to 6 make both the end faces 3a ~~and 3a~~ of the semiconductor multilayer 3 vertical to the layer plane of the semiconductor multilayer, and furthermore, both the end 6 planes 3a ~~and 3a~~ are required to be parallel to each other.

The ~~monocrystal~~ single crystal sapphire substrate to be used for the semiconductor laser element ~~is desired to~~ should be vertical especially between the major plane 11 for forming the semiconductor multilayer and the cleavage plane of both the end faces. Such relation is given in the orientation relation wherein the major plane is ~~made an~~ plane A, and the plane vertical to the major plane becomes ~~the~~ plane R. As shown in Fig. 8, the angle between the axis C of the ~~monocrystal~~ single crystal and the plane vertical to the major plane (plane A) becomes 32.383°, the plane vertical to the major plane becomes a cleavage plane parallel to the plane R.

As shown in Fig. 4, the ~~monocrystal~~ single crystal sapphire substrate 10 to be used for the laser diode is made the reference plane 12 by the previous formation of any end plane of the substrate precisely parallel to the plane R on the rectangular substrate. Form the semiconductor multilayer 30 on the ~~monocrystal~~ single crystal sapphire substrate, and then, draw the microcrack ~~line~~ lines parallel to the reference plane ~~by plural~~ at intervals of the distance between the reflection planes of the resonator. Then, apply bending stress for spreading the microcrack line, and the crack with the microcrack line as a starting point is developed in the thickness direction along the plane R, and the sapphire substrate and the semiconductor multilayer connected the sapphire substrate are continuously cleaved.

The cleavage plane 14 of the sapphire substrate is extremely smooth at ~~in~~ the atomic level as described above, and the cleavage plane of the semiconductor multilayer formed at the same time is also a smooth mirror plane ~~extremely higher~~ at the atomic level, so as to be ~~sufficiently~~ used as the reflection planes 3a ~~and 3a~~ of the resonator. The microcrack lines can be formed on the substrate in parallel ~~by plural~~ at intervals between the opposite reflection planes of the resonator. The substrate can be cleaved and divided sequentially along each microscopic ~~microscopical~~ line such that ~~the~~ reflection planes of high ~~plane higher in~~ parallelism can be provided. Therefore, a plurality of laser diodes of increased efficiency ~~of the laser beam~~ can be manufactured ~~manufacture~~.

A single crystal ~~monocrystal~~ substrate for laser diode use and a method of manufacturing the laser diode using it will be described hereinafter.

Concretely, a laser diode provided now is composed of a gallium nitride system compound semiconductor

$((Al_xGa_{1-x})_y In_{1-y} N ;\ 0 \le x \le 1,\ 0 \le y \le 1)$

of double hetero junction structure with an activated layer surrounded by ~~being grasped with~~ layers having a forbidden band width larger than the forbidden band.

Referring now to the laser diode, Fig. 6 shows a perspective view of the essential portions and Fig. 7 shows

a sectional view thereof. The single crystal ~~monocrystal~~ sapphire substrate 1 has the major plane as the plane A and the plane R cut into a plate vertical to the major plane from the sapphire single crystal ~~monocrystal~~ as shown in Fig. 8. The laser diode is provided with a buffer layer 2 composed of AlN on the major plane 11 of the single crystal ~~monocrystal~~ sapphire substrate 1, and is provided with a semiconductor multilayer 3 ~~for~~ constituting ~~composing~~ the laser element on the buffer layer 2.

The multiple layer 3 comprises a n^+ layer 31 composed of a Si doped n^- Calcium nitride ~~GaN~~ layer formed on the whole ~~plane~~ of the buffer layer 2, an electrode 41 on the n^+ layer 31, a n layer 32 composed of a Si doped $Al_{0.9}Ga_{0.1}N$ layer formed on the n^+ layer 31 except for an ~~the~~ electrode 41, an activated layer 33 composed of Si doped GaN layer, a p layer 34 composed of a magnesium doped $Al_{0.9}Ga_{0.1}N$ layer, a SiO_2 layer 35 for covering it, and an electrode 42 connected with the window portion of the SiO_2 layer 35.

The manufacturing process comprises washing the single crystal ~~monocrystal~~ sapphire substrate 1 with an organic solvent, then arranging in the crystal growth portion within the crystal growing apparatus, heating to approximately 1200°C in a ~~the~~ hydrogen atmosphere by a vacuum-exhausting operation, and removing hydrocarbon attached to ~~onto~~ the surface of the substrate.

The substrate 10 is heated to 600°C, growing an AlN layer of about 50 nm in thickness on the major plane 11 (namely, the plane A) of the substrate by suppling ~~the~~ trimethylene aluminum (TMA) and ammonia as a buffer layer 2. Trimethylene gallium (TMG), ~~the~~ ammonia and silane are supplied with the temperature of the substrate at ~~being~~ 1040°C to form a n^+ layer 31 composed of a Si droped n-GaN layer.

The substrate 10 is taken out of the growth furnace and one portion of the surface of the n^+ layer 31 is made with SiO_2 and then, is heated again within the growth furnace to 1040°C to supply the TMA, TMG and silane. An ~~A~~ n layer 32 composed of Si doped $Al_{0.9}$ $Ga_{0.1}$ N layer of 0.5 µm in thickness.

Furthermore, the TMG and silane are supplied to form activated layer 33 composed of Si doped GaN layer of 0.2 µm in thickness. Then, ~~supply the~~ TMG and Cp_2 Mg (bis-cyclopenta-dienyle-magnesium) are supplied to form the a p layer 34 composed of a magnesium doped $Al_{0.9}$ $Ga_{0.1}$ N layer of 0.5 µm in thickness.

After removal of ~~Remove~~ SiO_2 used as a mask by hydrofluoric acid ~~system~~ etchant, ~~and the~~ a SiO_2 layer 35 is piled on the a p layer 34. Then, a long strip of window of 1 mm in length and 80 µm in width is opened to apply an electronic line irradiation upon the p layer 34 in vacuum as the p layer 34 shows p - conduction. Then, metal electrodes 31 and 31 are connected

respectively with the window portion of the p layer 34 and the n^{+} layer 31.

Since the multilayer 3 of the semiconductor is formed on the major plane 11 of the single crystal ~~monocrystal~~ sapphire substrate 1 in this manner, the substrate and the multiple layer are cleaved, divided simultaneously integrally along the plane R of the substrate such that laser diode provided with the reflection plane on the end face shown in Figs. 6 an 7 can be obtained.

Strictly speaking, in the laser diode composed of the gallium nitride system compound semiconductor $((Al_xGa_{1-x})_y In_{1-y} N$, the cleaved plane of the semiconductor multilayer is out of the cleaved plane of the sapphire crystal which is a substrate. The direction of cleaving the substrate is inclined by 2.5 through 3.5° from the plane R of the sapphire crystal and simultaneously, is inclined by 59.5 through 60.5° from the plane C. The cleavage plane of the semiconductor multilayer is found ~~out~~ suitable to ensure the higher smooth property. The cleaving in this direction assumes somewhat stair shape in the cleavage plane of the sapphire substrate, and the cleavage plane of the semiconductor multilayer becomes smoother.

The cleavage of such direction has the microscopic groove of about 10 through 200 μm in depth formed previously for the angle relation on the reverse plane side

of the substrate and is cleaved along the groove at the division after the formation of the semiconductor multilayer. Also, as described above, a method of forming linear microcrack lines with a diamond needle point pen and ~~giving~~ Providing mechanical or thermal stres~~sing~~ to it.

Although in the above example, the major plane for forming the semiconductor multilayer of the ~~monocrystal~~ single crystal sapphire substrate is made an plane A, the major plane 11 can be made a plane C as shown in Fig. 5. In this case, the plane R which is a cleavage plane is not vertical to the major plane 11, but has an inclination of about 57.62°. Even in this case, the plane can be cleaved along the plane R and the substrate can be divided, so as to obtain the smooth division plane. The major plane of the substrate can be made planes except for plane A, plane C. It is confirmed that even in any case, no influences are ~~given to~~ Provided by the crystal orientation of GaN grown on the major plane.

In the other embodiments of the ~~monocrystal~~ single crystal sapphire substrate of the invention, Si can be grown on the substrate to make a SOS (Silicon on sapphire) device with the use of the ~~monocrystal~~ single crystal sapphire substrate 1, LED, a light emitting device, such as laser diode or the like can be made by formation of the semiconductor thin film such as SiC system ZnSe system, Zn system, a SAW (Surface Acoustic Wave) filter by the formation of the piezo-electric thin

film such as ZnO, AlN or the like, ~~form the~~ superconductor thin film such as $TiSrO_3$ or the like, and ~~form the~~ thin film such as HgCdTe or the like. Furthermore, the ~~monocrystal~~ single crystal sapphire substrate 10 can be ~~applied~~ used even for the substrate of a hybrid integrated circuit.

Furthermore, the ~~monocrystal~~ single crystal sapphire substrate of the invention, when the thin film or the element pattern are formed as described above, and then, are divided into chip shape into the semiconductor parts or the other electronic parts, can conduct the division of the ~~monocrystal~~ single crystal sapphire substrate with higher precision, quickly and in mass production by the application of the dividing method of the invention using the cleaving of the plane R. Also, efficient dividing of the substrate can be conducted by the formation of the reference plane vertical or parallel to the plane R on the ~~monocrystal~~ single crystal sapphire substrate. As the division plane is a smooth plane of high precision in the division plane, the semiconductor element, electronic parts of high performance can be obtained.

Since the invention has a reference plane parallel to or vertical to the plane R on the ~~monocrystal~~ single crystal sapphire substrate as described in detail above, the direction of plane R to be divided can be identified easily, so as to efficiently divide with the maximum use of the area of the ~~monocrystal~~ single crystal sapphire substrate.

According to the invention, the ~~monocrystal~~ single crystal sapphire substrate can be divided into many substrates provided with smooth cleavage plane high~~er~~ in precision only with a step of cleaving the sapphire ~~monocrystal~~ single crystal along the plane R, so as to use this process for mass production of the semiconductor element and other electronic parts. Since an acute edge can be formed with the division of the sapphire ~~monocystal~~ single crystal into smooth cleavage plane of high~~er in~~ precision, the sapphire ~~monocrystal~~ single crystal can be used as a component member for sapphire cutter or the like.

Further, the semiconductor laser element is a laser diode, which is provided with the plane R in the thickness direction of the ~~monocrystal~~ single crystal sapphire substrate, and has a semiconductor multilayer, for constituting the laser light emitting element, formed on the major plane. Since the cleaved plane of the semiconductor multilayer connected with the cleavage plane with the sapphire substrate being cleaved along the plane R is made a reflection plane of the resonator, the light emitting element can be made higher in light emitting efficiency, because the surface smoothness of the reflection plane is higher and the parallelism of both the reflection planes is higher.

Furthermore, in a method of manufacturing the semiconductor laser element comprises the steps of forming the semiconductor multilayer for composing the laser light

emitting element on the major plane of the single crystal ~~monocrystal~~ sapphire substrate provided with the plane R in the thickness direction, cleaving the sapphire substrate along the plane R, making the cleavage plane of the semiconductor multilayer connected with the cleaved plane the reflection plane of the resonator, the surface smoothness of the reflection plane is higher, the parallelism of both the reflection plane is higher, and the cleaving along the plane R is extremely easy ~~easier~~ to conduct, thus improving the working property and the productivity of the laser diode manufacturing operation.